Appendix C: Refinery Energy and Global Warming Impacts and Emissions

We estimated the increase in energy consumption in refineries expected to occur from desulfurizing gasoline to 30 ppm by analyzing the specific impact on PADD 3 refineries in 1997. We simplified our methodology here relative to that used for the cost analysis. We estimate the energy impact of desulfurizing gasoline under two scenarios. The first assumes that refiners will use the improved desulfurization technologies discussed in Chapter IV.B. This represents the near term scenario, when refiners are projected to use a mixture of proven, improved, and adsorption technologies. The second scenario assumes that refiners will use the advanced adsorption technologies also discussed in that chapter. This represents the long term scenario, when refiners are projected to use only the adsorption technologies. We use 1997 as the base year for this analysis because that is the base year of the cost calculation, which is a basis for this analysis, and because of the uncertainty in projecting U.S. global warming gas emissions in future years.

To determine the percentage increase in refinery energy consumed by desulfurizing gasoline, we first established the baseline energy consumption by PADD 3 refineries using 1994 Energy Information Administration data, which is the most recent energy consumption data available. We project the baseline energy consumption of PADD 3 refineries from 1994 to 1997 using an estimated increase in energy consumption of 6 percent, which is based on 2.05 percent increase in increased refinery throughput per year. This PADD 3 energy consumption calculation is summarized below in Table V-46. The energy consumed by PADD 3 refineries in 1997 is estimated to be about 1,500 trillion BTUs.

Table C-1. Energy Consumed by PADD 3 Refineries in 1994, Projected to 1997

Energy Type	Energy Consumed	BTU Value	MMMBTUs Consumed
Crude Oil	0 MBbls	-	0
LPG	660 MBbls	3.64 MMBtu/Bbl	2399
Distillate	54 MBbls	5.83 MMBtu/Bbl	315
Residual Oil	998 MBbls	6.29 MMBtu/Bbl	6274
Still Gas	112,538 MBbls	6.00 MMBtu/Bbl FOE	675,200
Petroleum Coke	38,152 MBbls	6.02 MMBtu/Bbl FOE	229,800
Natural Gas	487,115 MM Cuft	1.03 MBtu/CuFt	501,200
Coal	0 MStTons	-	0
Purchased Electricity	20,602 MMKwH	3.41 MBtu/KwH	70.3
Purchased Steam	11,970 MMLbs	0.809 MBtu/Lb	9680
Hydrogen	68,962 MMScf	0.305 MBtu/Scf	21,000
Other Products	252 MBbls	6.00 MBtu/Bbl FOE	1510
Total in 1994			1,438,000
Total in 1997 (Estimated)			1,528,500

The total amount of energy consumed to desulfurize gasoline down to 30 ppm target is calculated by adding up the fuel gas, steam and electricity, in terms of British thermal units (BTUs) consumed, for the desulfurization unit, hydrogen production and octane makeup . First we estimated the energy consumed running both the CDTECH and Octgain 220 processing units. Consistent with how the cost of desulfurization was estimated for these improved technologies, each desulfurization technology was presumed to handle half of PADD 3's desulfurization needs. Then the energy consumed for recovering octane and producing hydrogen demand is calculated.

Appendix C: Refinery Energy and Global Warming Impacts and Emissions

For both CDTECH and Octgain, we presumed that reformer capacity[1] was available to make up the octane lost from desulfurization. We accounted for the amount of hydrogen that the reformer would produce and by subtracting the reformer production from the hydrotreater demand, we estimated the amount of hydrogen which had to be provided by an existing hydrogen plant. Finally, half of the Octgain desulfurization processes installed are presumed to need splitters, or distillation columns, to fractionate the FCC gasoline. This additional energy demand is accounted for as well. A summary of the estimated CDTECH and Octgain energy and hydrogen demands in PADD 3 is summarized in Tables V-47 and V-48, respectively.

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[1] According to the 1996 API/NPRA survey of gasoline quality and refinery operations, spare reformer capacity is available in the U.S. If a particular refiner has no spare reformer capacity, then the energy consumed and global warming emissions emitted can then be assumed to be emitted by an expanded reformer, or other octane generating units which likely consume less energy than the reformer due to their less severe operating conditions.

Table C-2. Estimated Annual Energy and Hydrogen Demand of CDTECH Desulfurization Units for Half of PADD 3

CDTECH Utility Demands	Process Demand	Yearly Throughput	BTU Conversion Factor	Energy and Hydrogen Consumed
Electricity	0.44 KwH/Bbl	273 MMBbls	3.41 MBtu/KwH	410 MMMBtu
Fuel Gas	41250 Btu/Bbl	273 MMBbls	-	11,250 MMMBtu
Hydrogen	102 Scf/Bbl	273 MMBbls	-	27,800 MMScf
Reformer		Hydrogen	Produced	12,320 MMScf
Electricity	2.6 KwH/Bbl	12 MMBbls feed	3.41 MBtu/KwH	105 MMMBtu
Fuel Gas	0.06 FOE/Bbl	12 MMBbls feed	6 MMBtu/Bbl	4350 MMMBtu
Steam	94 Lb/Bbl	12 MMBbls feed	0.809 MBtu/Lb	1100 MMMBtu
Hydrogen Plant		Hydrogen	Produced	14,180 MMScf
Fuel Gas	0.11 FOE/Bbl	8.5 MMBbls H2	6 MMBtu/Bbl	5680MMMBtu
Electricity	1.69 KwH/Bbl	8.5 MMBbls H2	6 MMBtu/Bbl	50 MMMBtu
Total				22,950 MMMBtu

Table C-3. Estimated Annual Energy and Hydrogen Demand of OCTGAIN Desulfurization Units for Half of PADD 3

OCTGAIN 220 Utility Demands	Process Demand	Yearly Throughput	BTU Conversion Factor	Energy and Hydrogen Consumed
Electricity	1.55 KwH/Bbl	213 MMBbls	3.41 MBtu/KwH	1440 MMBtu
Fuel Gas	44500 Btu/Bbl	213 MMBbls	-	9470 MMMBtu
Steam	0 Lb/Bbl	213 MMBbls	0.809 MBtu/Lb	0 MMMBtu
Hydrogen	130 Scf/Bbl	213 MMBbls	-	27,700 MMScf
Splitter			-	
Electricity	0.17 KwH/Bbl	273 MMBbls	3.41 MBtu/KwH	80 MMMBtu
Fuel Gas	0 FOE/Bbl	273 MMBbls	6 MM Btu/Bbl	0 MMMBtu
Steam	45 Lb/Bbl	273 MMBbls	0.809 MBtu/Lb	5960 MMMBtu
Reformer		Hydrogen	Produced	1,140 MMScf
Electricity	2.6 KwH/Bbl	1.2 MMBbls	3.41 MBtu/KwH	11 MMMBtu
Fuel Gas	0.06 FOE/Bbl	1.2 MMBbls	6 MM Btu/Bbl	445 MMMBtu
Steam	94 Lb/Bbl	1.2 MMBbls	0.809 MBtu/Lb	94 MMMBtu
Hydrogen Plant		Hydrogen	Produced	26,600 MMScf
Fuel Gas	0.11 FOE/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	9040 MMMBtu
Electricity	1.69 KwH/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	75 MMMBtu
Total				26,600 MMMBtu

We used the same methodology to estimate the energy consumed for the adsorption technologies by Black and Veatch and Phillips, with each presumed to desulfurize half the gasoline pool. Those estimates are summarized in Tables V-49 and V-50.

Table C-4. Estimated Annual Energy and Hydrogen Demand of Black and Veatch Desulfurization Units for Half of PADD 3

Black and Veatch Utility Demands	Process Demand	Yearly Throughput	BTU Conversion Factor	Energy and Hydrogen Consumed
Electricity	1.92 KwH/Bbl	272 MMBbls	3.41 MBtu/KwH	1790 MMBtu
Fuel Gas	24100 Btu/Bbl	272 MMBbls	-	6580 MMMBtu
Steam	0 Lb/Bbl	272 MMBbls	0.809 MBtu/Lb	0 MMMBtu
Hydrogen	14 Scf/Bbl	272 MMBbls	-	3900 MMScf
Hydrogen Plant		Hydrogen	Produced	3900 MMScf
Fuel Gas	0.11 FOE/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	1330 MMMBtu
Electricity	1.69 KwH/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	11 MMMBtu
Diesel Hydrotreater				1170 MMMBtu
Total				10,900 MMMBtu

**Table C-5. Estimated Annual Energy and Hydrogen Demand of Phillips
Desulfurization Units for Half of PADD 3**

Phillips Utility Demands	Process Demand	Yearly Throughput	BTU Conversion Factor	Energy and Hydrogen Consumed
Electricity	0 KwH/Bbl	272 MMBbls	3.41 MBtu/KwH	1790 MMBtu
Fuel Gas	49400 Btu/Bbl	272 MMBbls	-	6580 MMMBtu
Steam	0 Lb/Bbl	272 MMBbls	0.809 MBtu/Lb	0 MMMBtu
Hydrogen	70 Scf/Bbl	272 MMBbls	-	19,100 MMScf
Reformer		Hydrogen	Produced	8590 MMScf
Electricity	2.6 KwH/Bbl	9.3 MMBbls	3.41 MBtu/KwH	83 MMMBtu
Fuel Gas	0.06 FOE/Bbl	9.3 MMBbls	6 MM Btu/Bbl	3350 MMMBtu
Steam	94 Lb/Bbl	9.3 MMBbls	0.809 MBtu/Lb	847 MMMBtu
Hydrogen Plant		Hydrogen	Produced	15,750 MMScf
Fuel Gas	0.11 FOE/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	3580 MMMBtu
Electricity	1.69 KwH/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	30 MMMBtu
Total				21,400 MMMBtu

As these tables show, the average increase in energy consumption for the improved gasoline desulfurization technologies to meet a 30 ppm gasoline sulfur program, including the energy needed to provide hydrogen and make up octane loss, is estimated to be about 50 trillion BTUs based on 1997 volumes. This increase in energy use is about 3.2 percent of the baseline PADD 3 refining industry energy consumption.

For the U.S. outside of California, the refining industry is estimated to consume 3000 trillion BTUs per year.[2] Thus the increase in energy demand for the U.S. refining industry, based on PADD 3 and using the 3.2 percent factor calculated above, is estimated to be about 96 trillion

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[2]This estimate is based on the presumption that PADD 3 consumes 50 percent of the energy in the U.S. outside of California.

BTUs per year.

In future years (i.e., after 2019), assuming that all FCC gasoline desulfurization is switched over to the adsorption desulfurization technologies, PADD 3 refiners are expected to consume 32 trillion BTU's over the baseline, which represents a 2.1 percent increase in PADD 3 refinery energy demand. Projecting this PADD 3 energy demand to the entire U.S., and based on the adsorption technologies, we estimate that the U.S. refining industry would consume an additional 63 trillion BTUs of energy to desulfurize gasoline based on a 1997 baseline.

We next estimated the amount of global warming gas emissions that would be emitted to meet the proposed 30 ppm gasoline sulfur standard. The basis for the estimate is an estimate of carbon dioxide emissions emitted from the combustion of fuels, which is the source of most refinery energy and, thus, is presumed to be the source of all refinery emissions of carbon dioxide. The carbon dioxide emission factor is estimated to be 65,000 grams of CO_2 per million Btu of fuel consumed, which is based on the combustion of half natural gas and half liquid petroleum gas (LPG is presumed to emit the same quantity of carbon dioxide per volume fuel consumed as refinery plant gas).[1] For simplicity, this analysis assumes that all BTUs consumed in a refinery are produced by these fuel sources. On this basis, CO_2 emissions from all U.S. refineries would increase by 6.7 million tons per year in the 1997 base year based on the improved desulfurization technologies, and CO_2 emissions would increase by 4.2 million tons in the 1997 base year based on the adsorption technologies.

The increase in CO_2 emissions for installing improved desulfurization technologies is a one-time step increase in CO_2 emissions which represents 0.12 percent of the U.S. CO_2 emissions inventory, which is 5.4 billion tons of CO_2 per year in based on 1997 emissons.[2] This increase also represents about 9 percent of the total projected increase in U.S. CO_2 emissions in a single year, which is about 70 million tons per year in 1997. Based on our presumption that the adsorption technologies will replace the mix of proven and improved desulfurization technologies (expected to occur after 2019), worldwide CO_2 emissions are projected to be 0.08 percent higher than the baseline due to the U.S. desulfurization program, which is 60 percent (or 40 percent less) of the total projected one-time increase in U.S. CO_2 emissions based on the mix of desulfurization technologies which we presume to be used at the outset of the program. The increase in energy consumed and carbon dioxide emissions is summarized in Table V-51.

Table C- 6. Increase in Energy Consumed and Carbon Dioxide Emissions Due to Desulfurizing Gasoline (1997 energy use and emissions)

	Improved Desulfurization Technologies	Adsorption Desulfurization Technologies
Increase in Energy Consumed (trillion Btu) Percent Increase in U.S. Refining Industry Energy Consumed	96 3.2	63 2.1
Increase in CO2 Emissions (million tons) One-Time Percent Increase in Yearly U.S. CO2 Emissions	6.7 0.12	4.2 0.08

The desulfurization of gasoline will increase emissions of conventional pollutants from refineries. At a minimum, desulfurizing gasoline will require the addition of a naphtha hydrotreater. However, refiners will need a source of hydrogen and make up the loss of octane. A likely way for refiners to make up that lost octane is to increase the feed to an existing reformer. In addition to the octane boost, the reformer also provides a source of hydrogen. If the amount of hydrogen provided by the reformer is insufficient, the refiner is assumed to either produce more hydrogen from an existing hydrogen plant, or install another hydrogen plant to provide the balance of hydrogen.

Each of these units require heaters to provide heat for reactions. Heaters emit oxide of nitrogen (NOx) emissions, volatile organic carbon (VOC) emissions, carbon monoxide (CO), particulates and sulfur oxide (SOx). VOC emissions are also emitted from leaks from pipes, valves, pumps etc. of refinery units which process petroleum.

To estimate the increase in emissions from desulfurizing gasoline, we contacted Mobil Oil to obtain emissions information from Mobil on their Octgain unit in operation at their Joliet, Illinois refinery. Mobil provided information to us for a 25,000 barrel per day Octgain unit.[3] The information provided was expressed in aggregate emissions per year, emissions per pound of fuel gas consumed, and emissions per hour. We used the hourly emissions rate with the hourly heater energy consumption as a divisor. This ratio expressed the emissions rate in terms of the energy consumed in the heater, which allowed us to base our emissions analysis on the PADD 3 energy analysis summarized above.

Using the PADD 3 analysis above, we are presuming that the emissions per energy consumed ratio, which we calculate in the Table C-7 below, is the same for all desulfurization technologies. This assumption is reasonable since heaters should be essentially the same for any

refinery processing unit. Except for VOC emissions, we also assume that the emissions from the other units that provide octane and hydrogen can be estimated by the emission factors in Table C-7. Since hydrogen plants normally only react natural gas, and since the octane produced from the reformer is likely from a unit already present in the refinery, we do not expect any additional VOC emissions from these units. Consistent with that premise, we only account for the VOC emissions from the hydrotreating unit. The VOC emission values reflect our presumption that refiners have adopted, or will have adopted, leak detection and maintenance programs for significant VOC emission control, which is consistent with the environmental programs in place, or expected to be in place, in most refineries. We expressed the NOx emissions as a range; the larger number reflects Mobil's estimate of NOx emissions from a heater with conventional burners, and the lower number is our estimate of a heater with ultra-low burners (which incorporates a 75 percent reductions in emissions). The information provided by Mobil Oil and our recalculated emissions values are summarized in the following table.

Table C-7.   Pollutant Emissions from an Octgain unit

Pollutant	Emissions (lbs per hour)	Emissions (lbs per MMMbtu)
NOx*	6.19 - 1.55	140 - 35
VOC**	1.08	25
CO	1.55	35
Particulates	0.13	3.0
SOx	0.56	13

*   Emissions based on two different types of burners, the upper range value is for a conventional burner provided by Mobil Oil, lower range value is our estimate for a for an ultra-low NOx burner which emits 75 percent less NOx per unit energy consumed.
** Emissions based on a unit monitored with a leak detection and maintenance program.

Next we revisit the increased energy demand due to desulfurizing gasoline for PADD 3 from Tables C-2 through C-5 above which are based on the four desulfurization technologies which formed the basis for our energy analysis. Based on the estimated increased PADD 3 energy demand, we then estimate the increased energy demand and resulting emissions increases for an average-sized refinery, which would be producing about 70,000 barrels per day gasoline or refining about 133,000 barrels per day crude oil, and for the U.S. refining industry. Like the PADD 3 energy analysis, we aggregate the two improved desulfurization technologies for one estimate, and aggregate the two adsorption technologies for the second estimate.

The actual emission increases from any given refinery could be more or less than our

estimates, due to several refinery-specific factors, such as the specific type of gasoline desulfurization technology chosen, the actual amount of gasoline produced per barrel of crude oil, the refinery's baseline gasoline sulfur level, and the actual level of emissions control. Therefore, EPA's estimates should in no way be viewed as the actual level of emission increases from a given refinery, but rather, as a relative estimate of refinery emissions increases, for general comparison with the benefits of the Tier 2/gasoline sulfur program. The true emission increases can only be estimated by specific refineries as they prepare permit applications for gasoline desulfurization projects. Refiners have also indicated that they may be making modernizations, plant expansions, or debottlenecking changes along with gasoline desulfurization changes. All of these changes, while not attributable to the Tier 2/sulfur program, could nevertheless result in emission increases higher than EPA's estimates.

The emission estimates for an average-sized refinery and for the U.S. refining industry are summarized in Table C-8 below.

Table C-8. Projected Increased Energy Use and Increased Pollutant Emissions of an Average-Sized Refinery and the U.S. Refining Industry due to Meeting the 30 ppm Gasoline Sulfur Standard (2004)

Technology Name	Increased Energy Demand for PADD 3 (MMMBtu/yr)	Projected Increase in Energy Use and Emissions for an Average-Sized Refinery (Tons/year)	
Energy Demand (MMBtu/year)	53,200	1830	110,400
Improved Desulfurization Technologies CDTech & Octgain 220		NOx 130 - 32 VOC 11 CO 32 Particulate 3 SOx 12	NOx 7730 - 1930 VOC 670 CO 1930 Particulate 165 SOx 695
Energy Demand (MMBtu/year)	32,300	1110	72,500
Adsorption Desulfurization Technologies Black and Veatch & Phillips		NOx 80 - 20 VOC 7 CO 20 Particulate 2 SOx 7	NOx 5100 - 1270 VOC 440 CO 1270 Particulate 110 SOx 460

Appendix C: Refinery Energy and Global Warming Impacts and Emissions

This analysis shows that the projected increase in refinery emissions due to desulfurizing gasoline is trivial compared to the significant emission reductions expected from the tighter motor Tier 2 vehicle standards. For both NOx and VOC and considering emissions in 2010, the increased emissions from refineries is less than one quarter of one percent of the decrease in NOx emissions reductions due to motor vehicle standards. In future years, as Tier 2 vehicles phase into the fleet, emission reductions from motor vehicles are expected to outpace emission increases in the refinery, and as adsorption technologies replace proven and improved desulfurization technologies in future years, the difference is expected to be even greater.

Appendix C References

1.   Wang, M.Q., GREET 1.4 - Transportation Fuel-Cycle Model, Center for Transportation Research, Argonne National Laboratory.

2.   Emissions of Greenhouse Gases in the United States 1998, Energy Information Administration, October 1998.

3.   Chuba, Mike, OCTGAIN Environmental Impact Evaluation, January 19, 1999.